Progress Report

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DEVELOPMENT AND TESTING OF A SHORT-WAVE RADIATION MODEL FOR INTERPRETING ARM DATA

DOE Grant DE-FG02-97ER62363 before 3/31/2000
DOE Grant DE-FG03-00ER62931 after 3/31/2000

July 12, 2000

Scientific goals: To contribute to a better understanding of aerosol direct radiative forcing, to improve our understanding of the cloud horizontal inhomogeneities that affect atmospheric radiation, to improve our understanding of radiative properties of cirrus clouds; to develop and test parameterizations of radiation processes for use in GCMs and satellite remote sensing applications. These goals are being achieved through a combination of analyzing the ARM field data, modeling studies, and theoretical studies. We are relying heavily on the ARM CART site data to develop and test the cloud and radiation parameterizations. We now also initiate collaboration with a GCM center to examine the feedback of some important cloud radiation processes in climate system.

Accomplishments: 1) Using five years data set collected at the ARM SGP central facility, it is found that for the solar direct beam, the model agrees very well with the measured surface fluxes with a mean difference of 2.4 W m^{-2}, while for the solar downward surface diffuse flux, the mean difference between the model and observations is still 14 W m^{-2}. 2) Using cirrus microphysical properties derived from the ARM SGP CART site cloud radar, the OLR bias due to the cirrus horizontal inhomogeneity is examined for the first time, and it is found that the OLR biases due to the PPH assumption are ~14 W m^{-2}. The GCM parameterization to account for the effect of cloud horizontal inhomogeneity on the infrared fluxes has been developed and tested.

Progress for period from July 15, 1999 to July 15, 2000:

(1) The ARM SGP CART site has been collecting high quality surface radiative flux measurements for over five years. The array of radiometers and other atmospheric instrumentation provides an excellent opportunity for intercomparison studies involving the instruments and radiative transfer models. One of our studies has focused on the measurements of surface solar irradiances in 3604 clear sky 30-minute segments from January 1994 to September 1998. Careful consideration is given to the elimination of cloud contamination effects. Water vapor profiles from radiosondes and the microwave radiometer and aerosol optical depths measured at five wavelengths are input to the Fu-Liou radiative transfer model to provide a comparison with measurements.

For the direct beam, the model agrees very well with the measured surface irradiances with a mean excess of 2.4 W m^{-2}. An unexpected correlation was found between the model-measured direct irradiance difference and the surface air temperature, suggesting an uncorrected temperature effect in the pyrheliometer output. The modeled mean diffuse irradiance is still overestimated by 14.0 W m^{-2} after applying a correction for the night-time offset problem that is endemic to pyranometers.

Various hypotheses are examined to explain the diffuse discrepancy including modified aerosol properties or the presence of an unaccounted gas absorber. Although a number of hypotheses are still viable to explain the model-measured diffuse difference, the mean TOA (top of atmosphere) aerosol forcing ranges from -11.5 to -1.4 W m^{-2} between the various hypotheses. Our study does not support the idea of a water vapor continuum in the solar wavelengths to explain any significant portion of the observed bias. A five year climatology of the aerosol optical depth and Angstrom exponent is presented showing seasonal and annual trends. An increase in the Angstrom exponent from 1994 is observed in both the surface-based aerosol optical depth measurements and in the SAGE II satellite data.

(2) Clouds exhibit dramatic variabilities at spatial scales smaller than typical grid cells of large scale models used to study climate and weather. These unresolved cloud fluctuations are potentially important for parameterizations of both cloud radiative effects and cloud microphysical processes. At this stage, e.g., it is well known that neglect of cloud subscale variability can seriously bias model estimates of the disposition of solar radiation in the Earth-atmosphere system.

In the past few years a large research effort has gone into investigating solar radiative transfer for horizontally inhomogeneous clouds and developing techniques suitable for use in large scale models. By contrast, little attention has been given to the longwave radiative transfer within an inhomogeneous cloud. One of our research efforts here has examined the outgoing longwave radiation (OLR) bias due to the neglect of cloud horizontal inhomogeneities. It is argued that the OLR bias is most significant for cirrus clouds which are semi-transparent and located in the cold upper troposphere. Using two cirrus cases observed at the ARM SGP CART site by cloud radar, it is found that the OLR biases due to the PPH assumption are ~14 W m^{-2}, which are largely caused by the horizontal variation of cloud optical depth. It is also shown that in general, the OLR biases are strongly dependent on the mean and standard deviation of cloud optical depth and the cloud height. We have demonstrated that the gamma-weighted radiative transfer scheme, which is sufficient for GCM applications, can be used to account for the effect of cloud horizontal inhomogeneity on the infrared fluxes.

(3) The finite-difference time-domain (FDTD) technique has been examined for its suitability for studying the light scattering by highly refractive dielectric particles. It is found that for particles with large complex refractive indices, the FDTD solution of light scattering is sensitive to the numerical treatments associated with the particle boundaries. Herein, appropriate treatments of the particle boundaries and related electric fields in the frequency domain are introduced and

examined in order to improve the accuracy of the FDTD solutions. As a result, it is shown that for a large complex refractive index of 7.1499+2.914I, the errors in extinction and absorption efficiencies from the FDTD method are generally smaller than ~4%. The errors in the scattering phase function are smaller than ~5%. We conclude that the present FDTD scheme with appropriate boundary treatments can provide reliable solution for light scattering by nonspherical particles with large complex refractive indices.

(4) An efficient and accurate parameterization for the scattering process in the infrared has been developed and incorporated into the CCC GCM.

Electronic Figures: See attached three figures for the ARM presentation material.

Fig. 1. Comparison of solar direct surface flux between the model results and the BSRN pyrheliometer measurements at the ARM SGP central facility under clear sky conditions. Each point represents 30-minute average and the 3604 clear 30-minute segments cover the period from January 1994 to September 1998. We can see an excellent agreement between the model and the observation for the solar direct surface fluxes.

Fig. 2. Comparison of solar downward diffuse surface flux between the model results and the BSRN shaded pyranometer measurements at the ARM SGP central facility under clear sky conditions. Each point represents 30-minute average and the 3604 clear 30-minute segments cover the period from January 1994 to September 1998. The night-time offsets have been corrected from the observed data following the recommendation by E. Dutton. The mean difference between the model and the measurement is still 14 W m^{-2}.

Fig. 3. The outgoing longwave radiation bias due to the GCM plane-parallel homogeneous assumption as a function of the mean and standard deviation of cloud optical depth for (a) high cirrus clouds, (b) middle water clouds, and (c) low water clouds.

Refereed Publications acknowledging DOE Grant DE-FG02-97ER62363 and DOE Grant DE-FG03-00ER62931 for the current grant FY:

1)* Fu, Q., M.C. Cribb, H.W. Barker, S.K. Krueger, and A. Grossman, 2000: Cloud geometry effects on atmospheric solar absorption. *J. Atmos. Sci.*, 57, 1156-1168.

2) Li, J., and Q. Fu, 2000: Absorption approximation with scattering effect for infrared radiation. *J. Atmos. Sci.* (accepted).

3) Fu, Q., B. Carlin, and G. Mace, 2000: Cirrus horizontal inhomogeneity and OLR bias. Submitted to *Geophys. Res. Lett.*

4) Videen, G., W.B. Sun, Q. Fu, D.R. Secker, R. Greenaway, P.H. Kaye, E. Hirst, and D. Bartley, 2000: Light scattering from deformed droplets and droplets with inclusions: II. Theoretical treatment. Submitted to *Appl. Opt.*

5) Sun, W.B., and Q. Fu, 2000: Finite-difference time domain solution of light scattering by dielectric particles with large complex refractive index. Submitted to *Appl. Opt.*

6) Fu, Q., and G. Lesins, 2000: Five years of clear sky solar radiation measurements and aerosol forcing at the ARM SGP CART site. (in preparation).

*This paper was listed in the 1999 report as accepted.

Updating on the Status of Publications:

In the previous FY progress report, no papers were listed as submitted.

Below are the complete list of 1999 journal publications acknowledging ARM Grant DE-FG02-97ER62363:

1) Chylek, P., Q. Fu, W. Tso, and D.J.W. Geldart, 1999: Contribution of water vapor dimers to clear sky absorption of solar radiation. *Tellus*, 51A, 304-313.

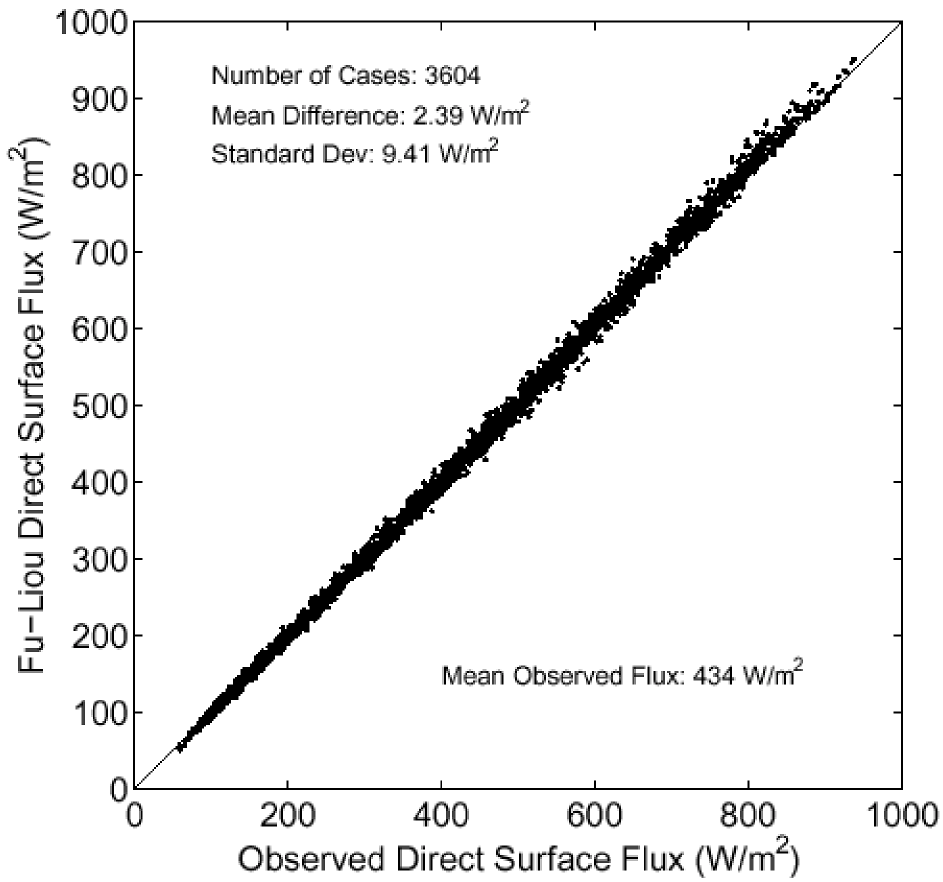
2) Sun, W.B., and Q. Fu, 1999: Anomalous diffraction theory for arbitrarily oriented hexagonal crystals. *J. Quan. Spectro. Rad. Trsnsfer*, 63, 727-737.

3) Fu, Q., W.B. Sun, and P. Yang, 1999: Modeling of scattering and absorption by nonspherical cirrus ice particles in thermal infrared wavelengths. *J. Atmos. Sci*., 56, 2937-2947.

4) Barker, H.W., and Q. Fu, 1999: Modeling domain-averaged solar fluxes for an evolving tropical cloud system. *Atmospheric and Oceanic Optics*, 12, 211-217.

5) Barker, H.W., G.L. Stephens, Q. Fu, 1999: The sensitivity of domain-averaged solar fluxes to assumptions about cloud geometry. *Q. J. Royal Meteorol. Soc*., 125, 2127-2152.

6) Sun, W.B., Q. Fu, and Z.Z. Chen, 1999: FDTD solution of light scattering by dielectric using PML ABC. *Appl. Opt.*, 38, 3141-3151.



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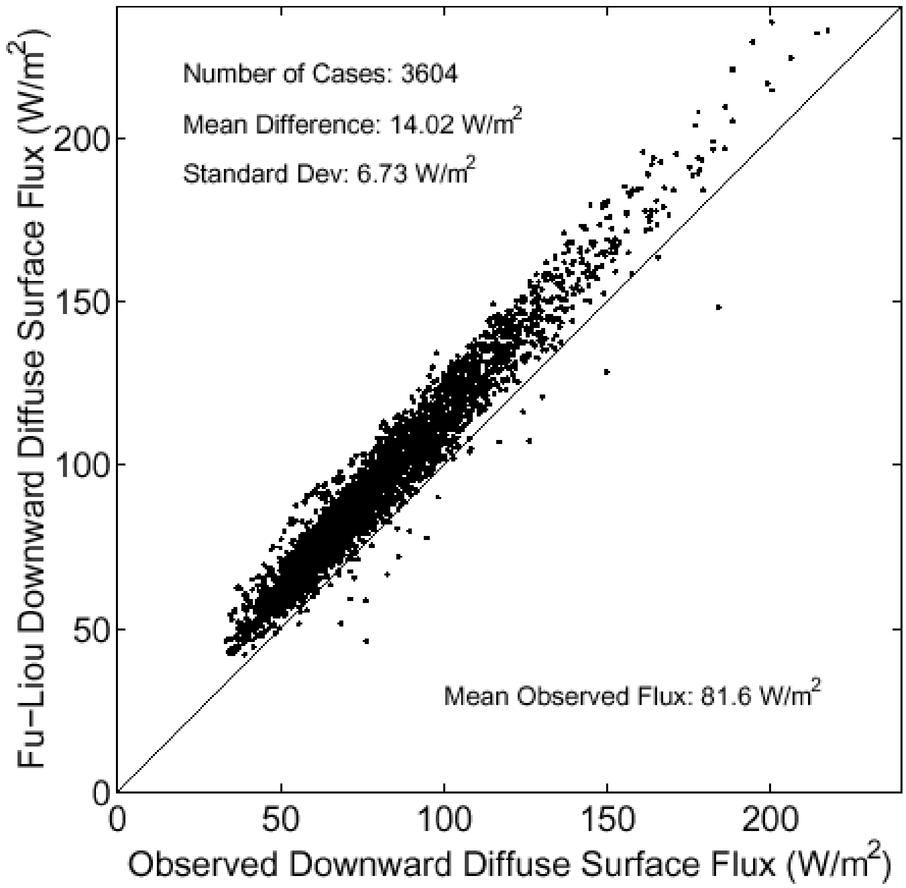

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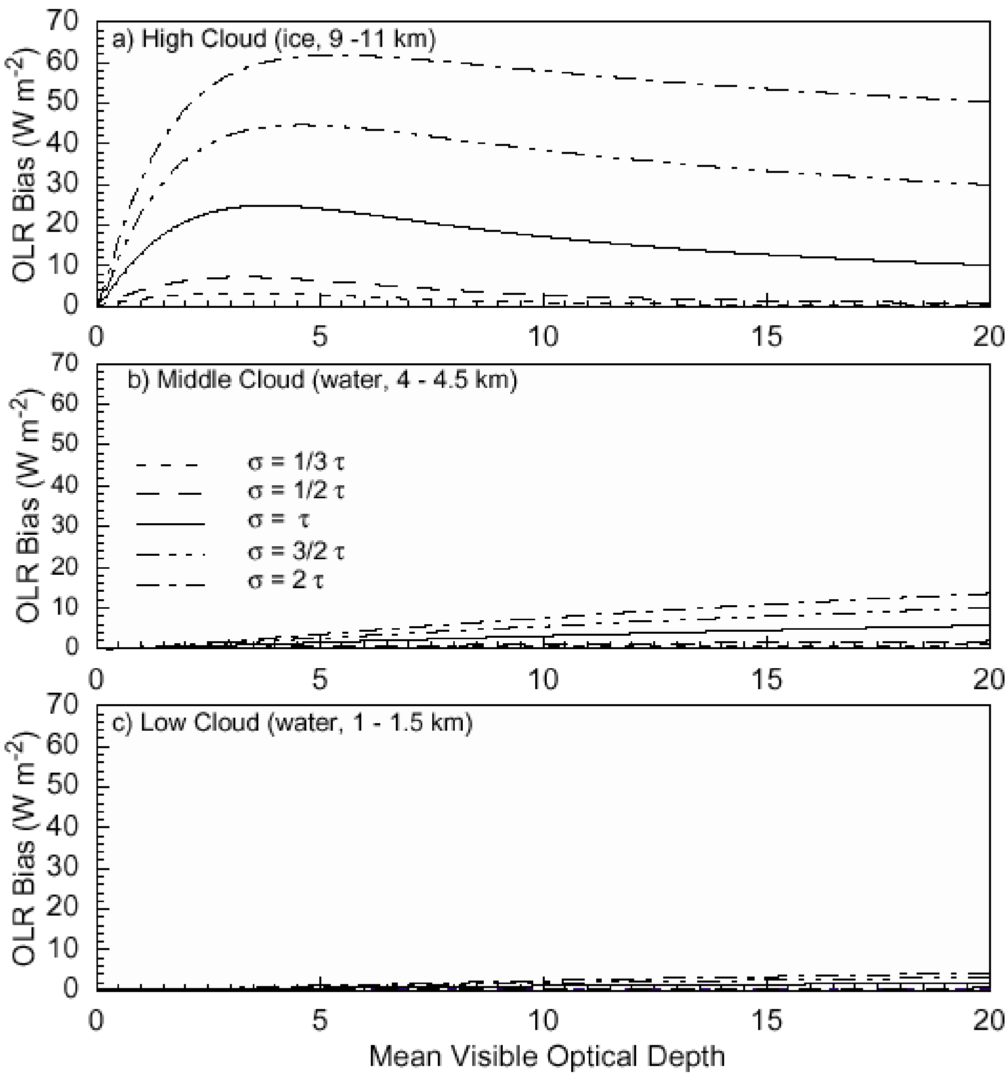

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